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AUTHOR Pelton, Rick; Espy, John
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ABSTRACT

This sixth in a series of seven modules for a course titled Nondestructive Examination (NDE) Techniques I explains radiographic inspection as a means of nondestructively examining components, assemblies, structures, and fabricated piping. The module follows a typical format that includes the following sections: (1) introduction, (2) module prerequisites, (3) objectives, (4) notes to instructor/student, (5) subject matter, (6) materials needed, (7) procedures, (8) data table, (9) reference materials, (10) test. (The course is one of fifteen technical courses for the second year of a two-year postsecondary curriculum in Nuclear Quality Assurance/Quality Control Technology.) (LRA)

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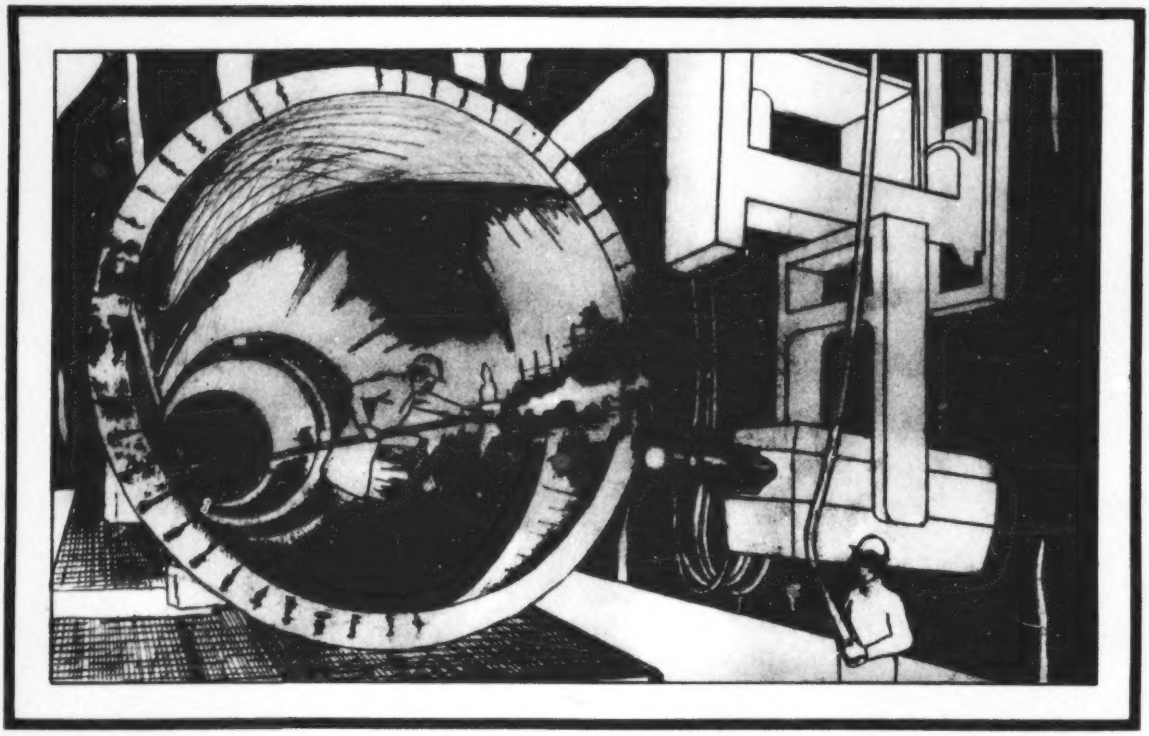
NUCLEAR TECHNOLOGY

COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

MODULE 26-6 Radiography Inspection



CE 024 251

GENERAL PHYSICS CORPORATION
Columbia, Maryland

COURSE MODULES

COURSE 26 NONDESTRUCTIVE EXAMINATION (NDE) TECHNIQUES I

Module 26-1	Visual Tests
Module 26-2	Leak Tests
Module 26-3	Hydrostatic Tests
Module 26-4	Liquid Penetrant Tests
Module 26-5	Fundamentals of Radiography
Module 26-6	Radiography Inspection
Module 26-7	Radiographic Specifications and Code Requirements

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This module was prepared for General Physics Corporation by Rick Pelton and John Espy, General Physics Corporation.

GENERAL PHYSICS CORPORATION

1979

INTRODUCTION

Radiographic inspection, as covered in this module, is a means of nondestructively examining components, assemblies, structures and fabricated piping, and is widely used in the construction, maintenance and repair of power plants and petro-chemical plants, and for many other industrial applications.

In the broadest sense, radiography includes fluoroscopy (the viewing of a real-time image on a fluorescent screen), and radiation gaging (the measurement of radiation intensity with electronic instruments), but this module deals only with the process which produces a permanent image on film.

Module 26-5, "Fundamentals of Radiography", is prerequisite for this module, which, when both are completed, will equip the trainee with the knowledge to select the radiation source appropriate for the application, select a suitable radiographic film, be aware of personnel safety requirements, perform the necessary calculations to determine radiographic exposures, properly arrange sources, specimens and films, and to evaluate probable causes and corrections for unsatisfactory radiographs.

MODULE PREREQUISITES

Module 26-5 "Fundamentals of Radiography".

OBJECTIVES

To satisfactorily complete this module, the trainee shall:

1. Demonstrate a knowledge of the fundamentals of radiography inspection by responding correctly to written exercises, which are similar to the questions included in the American Society for Nondestructive Testing SNT-TC-1A Level II certification written test.
2. Demonstrate a knowledge of exposure calculations and controls by performing calculations and/or determining: steel-equivalent thickness, absorber factors, source activity, source-to-film distances, gamma ray and x-ray exposure times.
3. Demonstrate a knowledge of exposure arrangements by answering written questions about typical arrangements, and labeling sketches of arrangements to show source location, penetrameter location and film location.
4. Demonstrate a knowledge of radiographic image defects and film artifacts by answering written questions about errors in techniques, film handling, and film processing.
5. As a laboratory exercise, given a metal part, such as a machined part, gear, welded pipe, or similar object by the instructor, the trainee shall prepare a diagram and procedure for radiographing the object, and using the information in this text, write a radiographic test report including the following detailed information:
   a. Source: type, strength, reason for selection.
   b. Test specimen: material type, thickness (area to be radiographed), absorber factor.
   c. Sketch of test arrangemetn: source location, film penetrameter.
   d. Exposure time and supporting calculations.
   e. Suggested film processing procedure.
   f. Recommended personnel safety precautions for radiation protection.

RADIATION SOURCE SELECTION

General

Most industrial radiography is performed with either x-ray machines used as radiation sources, or with gamma ray emitting radioisotopes. Commercial testing companies, which specialize in furnishing nondestructive testing services, may have several different sizes of x-ray machines, and several types and sizes of radioisotopes for use in providing a broad range of radiographic testing services for their customers. When such a variety of equipment is available, the radiographer can select the radiation source best suited for each specific application. In most industrial situations, however, only one or two radiation sources are available, and the radiographer has little or no choice. Nonetheless, the radiographer should be familiar with the energies emitted, penetrating capabilities, and other characteristics of the most commonly used radiation sources, and how to utilize those characteristics to the best advantage.

Radiation Source Energies

The production of x-rays is a function of the voltage on the x-ray tube: the higher the voltage, the shorter the wavelength of the radiation produced, and the greater the intensity and penetration power of the radiation. X-ray machines, then, are rated by the nominal maximum operating voltage of the particular x-ray tube, such as 150 KV (Kilovolt), 300 KV or greater.

The penetrating power or capability of commercial x-ray machines is shown in Figure 26-6-1, where the nominal x-ray tube operating voltage is plotted against the effective penetrating ability using film packs with (1) lead screens

and (2) fluorescent screens in radiographing steel specimens. Screen usage will be discussed later in this module. (Please refer to the next page for Figure 26-6-1.)

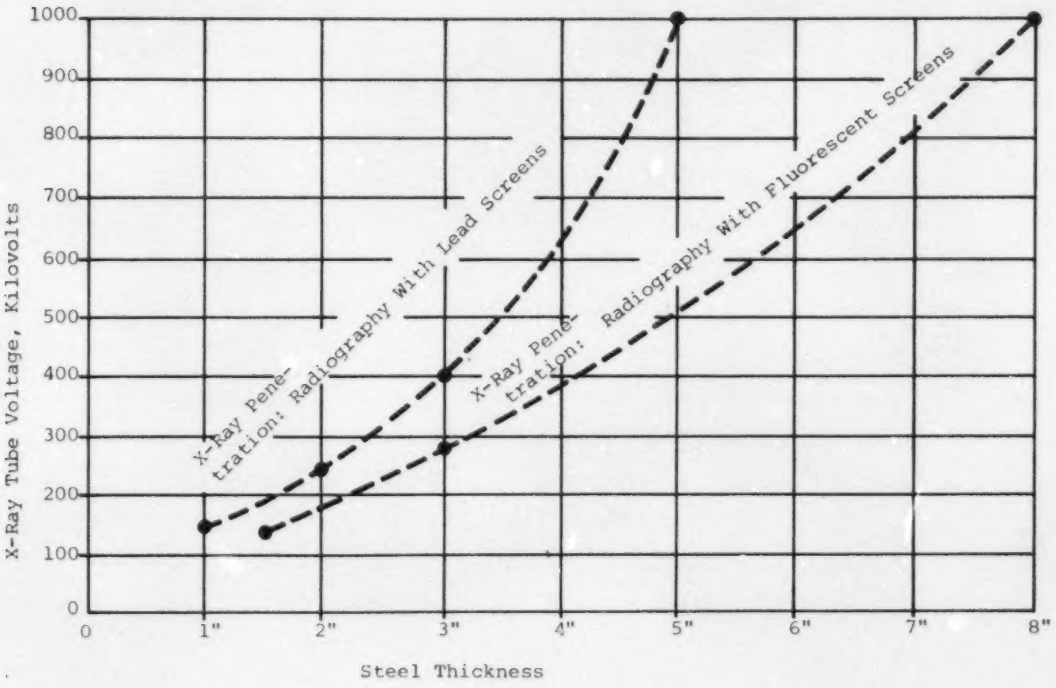


Figure 26-6-1. X-Ray Penetration in Steel: Radiographic Effectiveness

Gamma rays, emitted from radioisotopes, are expressed in terms of the energy of the individual quantum emitted, rather than wavelength. The unit of energy used is the electron volt (ev). In describing gamma radiation, multiples of electron volt terms are used, such as kilo-electron volts (kev) and million-electron volts (mev). (1 kev = 1,000 ev, and 1 mev = 1,000,000 ev) Some radioisotopes emit only

one-energy gamma rays, but others may emit two or more different-energy gamma rays. These energies are usually described in units of million-electron volts (mev). It is a property of such emitted radiation that the higher the gamma energy, the greater the penetrating power.

The characteristics of some gamma sources are listed in Figure 26-6-2.

Isotope	Half-Life	Gamma Energies Emitted (Mev)	Specific Activity Curies/Gram	Emissivity @ 1 Ft. R/Ci/HR
Cesium - 137	30 Years	0.66	Up to 22	4.20
Thulium - 170	120 Days	0.054 & 0.084		0.03
Iridium - 192	75 Days	0.137 to 0.651	Up to 500	5.92
Cobalt - 60	5.3 Years	1.33 & 1.17	Up to 150	14.53
Radium - 226	1620 Years	0.24 to 2.2	1	9.04

Figure 26-6-2 Characteristics of Gamma Ray Sources

The isotopes most frequently used as sources for industrail radiographic work are Cobalt-60 and Iridium-192. These isotopes are preferred for their:

- high gamma ray energy (penetrating power), and
- high specific activity (resulting in small source size).

Cobalt-60, with gamma energies of 1.17 and 1.33 Mev has penetrating power equal to that of a 2 million volt x-ray machine, and may be used effectively in radiographing steel section from 1-1/2" to 9" thick, with a sensitivity of 2%.

Iridium-192, with primary gammas of 0.33 and 0.48 Mev, and several near 0.6 Mev, has penetrating power approximately equal to that of a 500 kilo volt x-ray machine, and may be used in radiographing steel from 3/8" to 3" thick, with a sensitivity of 2%.

The penetrating power of any radiation is referred to as a relative hardness. Thus, very penetrating radiation is known as hard radiation, and less penetrating radiation is called softer radiation.

Summary

Applicability of radiation sources - The radiation sources in this section are listed in Figure 26-6-3 with their recommended ranges for radiographing equivalent steel materials. (Please refer to the next page for Figure 26-6-3.)

MATCHING RADIATION SOURCES TO SPECIMEN REQUIREMENTS

In selecting radiation sources, consideration must be given to specimen shape, configuration and location, and desired radiographic quality. Pipes, pressure vessels, valve bodies, structural steel welds and other typical specimens all require different "shooting" arrangements with respect to the radiation source location and placement. The actual location and elevation of the specimen, and interferences with other stationary piping and equipment are also factors which must be considered. In controlling radiographic quality, the source must be selected which will provide the required sensitivity and radiographic contrast. In using gamma sources, radiographic contrast can only be influenced by varying the exposure. In using x-ray machines, however, contrast is affected by both exposure and kilovoltage: an

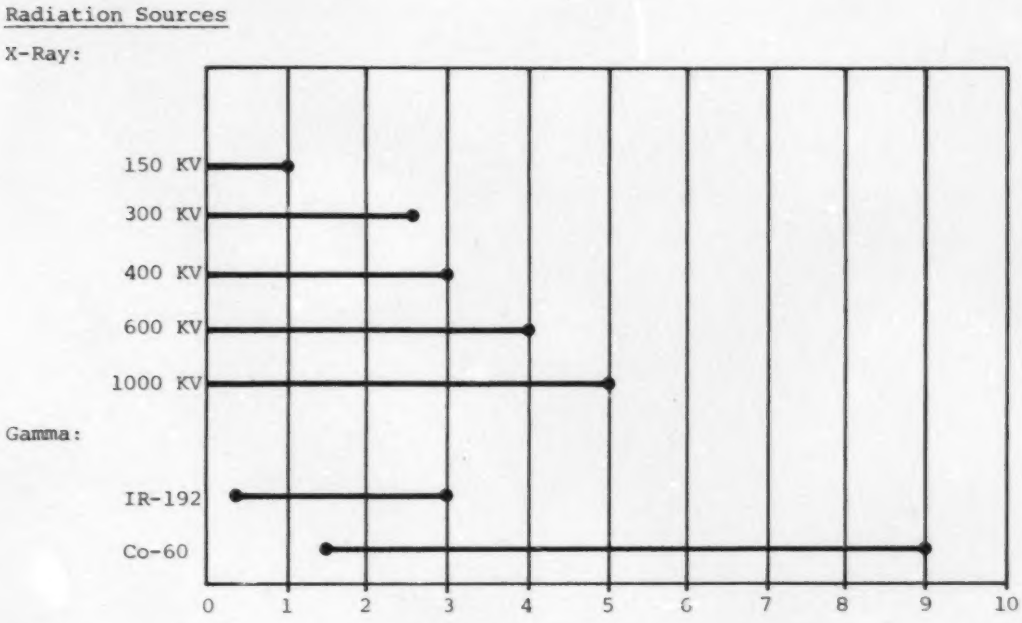


Figure 26-6-3 Radiation Source Applicability

increase in kilovoltage increases contrast, and a decrease in kilovoltage decreases contrast.

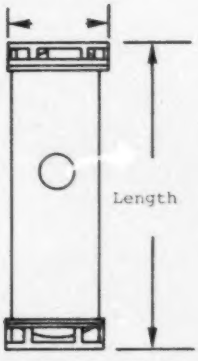
X-ray laboratories are suitable for radiographing specimens which can be moved to the facility. For this situation, an x-ray machine can be selected that will produce radiation capable of making the maximum required exposure, and the laboratory, or shielded area where the equipment will be used, designed accordingly.

Except for low voltage units, however, x-ray machines are large, heavy and unwieldy, and are unsuitable for use in many industrial situations. The units usually consist of a control panel, interconnecting cables, and an x-ray head, which must be set-up in such a manner as to direct the x-ray beam at the specimen target.

A typical x-ray control panel and head are shown in Figure 26-6-4, along with a chart of typical x-ray head sizes and weights.

X-Ray Control Panel

X-Ray Head



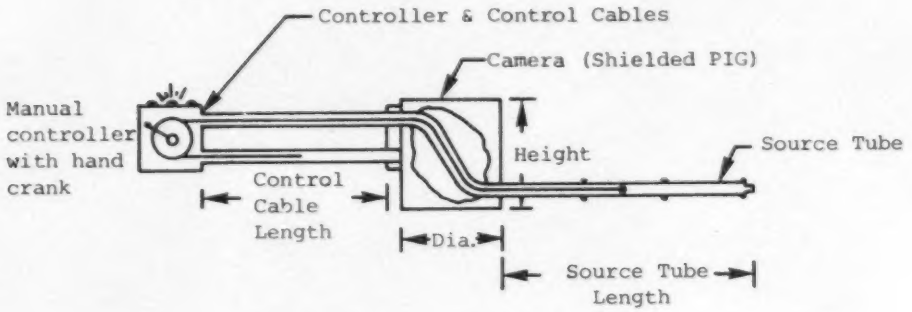
Typical X-Ray Head

KV.	DIA.	Length	Wt., Lbs.
150	10"	24"	55
200	12"	30"	75-90
225	12"	36"	75-110
250	12"	36"	90-125
300	13"	46"	105-150

Figure 26-6-4 X-Ray Machines

Radioisotopes for radiographic use are generally used with equipment which is more portable than the x-ray equipment. No external power is required, and the source is handled remotely by operating a controller. The controller is attached to the "camera" (shielded storage device or "pig") and causes the radioactive "source" to move out of the camera into the extended source tube, which has been positioned to locate the source for the effective exposure of the specimen.

Typical cameras, controls and source tubes for Ir-192 and Co-60 sources are described in Figure 26-6-5.



Gamma Source Camera & Attachments

Typical Equipment Specifications

Source	Camera			Control Cable Length	Source Tube Length
	Ht.	Dia.	Wt., #		
Ir-192, 35 Ci	7½"	5½"	25	25'	15'
Ir-192, 100 Ci	8"	5½"	32	25'	25'
Co-60, 5 Ci	12"	11"	150	30'	23'
Co-60, 50 Ci	20"	13"	300	30'	23'

Figure 26-6-5 Typical Gamma Source Equipment

It should be noted that the source tubes are flexible and may be moved in any direction from the camera. Heavy cameras, such as those for Cobalt-60 sources, are usually wheeled on a dolly as close to the specimen being radiographed as possible. Light weight cameras, such as those shown for Iridium-192, may be carried easily by the radiographer to the test location. In either case, the source tube can be positioned in virtually inaccessible or hard to reach locations where x-ray equipment could not be used. The size of the camera (shielded PIG) must be sufficient to provide proper biological shielding for the technician when it is not in use. A manual crank controller is generally used as is shown in Figure 26-6-5, thus enabling the user properly position the source and once again retract it into the shielded PIG. "Source-in" and "source-out" lights are employed to provide indication of source position.

FILM SELECTION AND USAGE

Film Types

Radiographic films are manufactured with different characteristics to suit different applications. Generally, they are classified by quality (grain size) and speed (relative sensitivity). The coarser the grain size of any film usually corresponds to a faster film speed, or greater sensitivity.

Contrast varies with film type, and generally increases with increasing density. A minimum film density of 1.5 is usually required for most industrial applications, and darker films are desirable if the viewing equipment has sufficient light intensity.

"Film factors" are statements of radiation dosage required to expose a film to a specified density compared to some other film accepted as a standard. Figure 26-6-6 shows relative film factors and comparative contrasts of typical films used by industry.

Film Type	Density			
	1.5	2.0	2.5	3.0
Medium Speed (Fine Grain) Kodak Industrex AA Dupont NDT 75 GAF 1600	3.6	5.1	6.6	14.9
Low Speed (Extra Fine Grain) Kodak Industrex M Dupont NDT 55 GAF 400	14.5	20.8	27.3	34.3

Figure 26-6-6 Film Factors (Estimated)

For medical radiographic work, a fast, coarse grain film is desirable for minimizing exposure times and the attendant absorption of harmful radiation by the patient.

In most industrial applications, however, fine grain or extra fine grain films are used, which provide greater contrast and higher radiographic quality.

It is advisable to refer to manufacturer's specifications for specific characteristics and comparison of grain sizes and relative speeds.

Film Packaging

Radiographic films are available in a variety of sizes and packages, the basic types being sheet films and roll films.

Both types are light sensitive and must either be purchased in individual, sealed, ready to use packets, or be purchased loose in light-tight cartons (e.g., units of 125 or 500 sheets per carton) and loaded into light proof envelopes called cassettes or other types of film holders in the protection of a darkroom, prior to use.

- Sheet Films - Sheet films are furnished in rectangular shapes and are available in widths from about 3-1/2 to 14 inches and lengths from about 7 to 17 inches. They may be purchased in loose, bulk packages, or in individual light proof packages, ready to use. The individual film packages are available as (1) single film sheet packs, for direct exposure techniques, and (2) lead packs, which contain a single film sheet inserted between two lead oxide screens, for intensification techniques. Both types of film packs eliminate the time-consuming process of darkroom loading of film holders and cassettes and protect the film from fingerprints and dirt up to the time the film is removed from the pack for processing.
- Roll Films - Roll Films are useful in radiographing circumferential welds and other long joints. Bulk roll films are available in various widths, and in various lengths up to about 550 feet. They may also be purchased pre-packed in plain, light-proof paper packs, and in lead-packs with lead oxide screens. Roll film packs such as these offer the same advantages and convenience as described for sheet film packs.

PERSONNEL SAFETY CONSIDERATIONS

The absorption of ionizing radiation produces physiological changes and damage to the human body. All personnel must therefore be protected from exposure to x or gamma radiation. Radiography must be conducted in restricted areas when possible, under controlled conditions, and under the supervision of properly qualified personnel.

The use of radioisotope sources (by-product materials) is controlled by the Federal Government. Specific licenses are required to use by-product materials. All persons who "manufacture, produce, transfer, receive, acquire, own, possess, use, import, or export" by-product material must have such a license. The regulations concerning the licensing of by-product material for use in radiography are contained in Title 10, Code of Federal Regulations, Parts 30 and 34.

The radiation safety requirements for radiographic operations, using radioisotopes, are contained in Title 10, Code of Federal Regulations, Part 34. The rules require the license to have operating, emergency and precautionary procedures to radiographic operators, including procedures for personnel monitoring, equipment security, radiation surveys and radiation monitoring.

Regulations and safety rules are drawn to limit personnel radiation exposures to a point far below danger levels and to afford acceptable protection for the general public of the United States. These rules are contained in Title 10, Code of Federal Regulations, Part 20.

The Federal Regulations described herein are specifically invoked for the use of by-product materials. The regulations are applicable to x-ray operations only when isotope radiography is also used. Even when a radiography program includes only x-ray equipment and operations, however,

the basic principles for personnel safety remain the same, and the rules should be used as guidelines for radiographic operations and a radiation safety program.

SUBJECT EXPOSURE CALCULATIONS AND CONTROL

Radiation Absorption Characteristics of Specimens

When x-rays or gamma rays strike a specimen, part of the radiation is absorbed by the material and part passes through. The radiation absorption is dependent on the specimen thickness, density and atomic nature of the material. The amount of absorption of x-rays is also a function of kilovoltage and penetrating power, as the absorption of gamma rays is a function of emitted energies and penetrating power.

To assist the radiographer in equating various materials, radiographic equivalence factors have been determined for different radiation sources. Some of these are listed in Figure 26-6-7.

NOTE: Steel is taken as the standard metal for the voltages and radioisotopes shown. The thickness of another metal is multiplied by the corresponding factor to obtain the approximately equivalent thickness of the standard metal (steel). The exposure required for this thickness of the standard metal is then used. This relationship of various materials to the radiation absorbance characteristics of steel is known as "steel equivalent thickness".

In calculating initial radiographic exposures using gamma-ray sources, it is convenient to use a chart of "absorber values" for determining absorber values for different radioisotopes and for different material thicknesses. The absorber values for sources of Ir-192 and Co-60 have been

Material	X-Rays				Gamma-Rays	
	150 KV	220 KV	400 KV	1000 KV	Ir-192	Co-60
Steel	1.0	1.0	1.0	1.0	1.0	1.0
2024 Alum. Alloy	0.16	0.22			0.35	0.35
Copper	1.6	1.4	1.4		1.1	1.1
Inconel x Alloy	1.4	1.3	1.3	1.3	1.3	1.3
Zirconium	2.3	2.0		1.0		
Lead	14	12		5	4.0	2.3

Figure 26-6-7 Approximate Radiographic Equivalent Factors (Or Steel Thickness Factors)

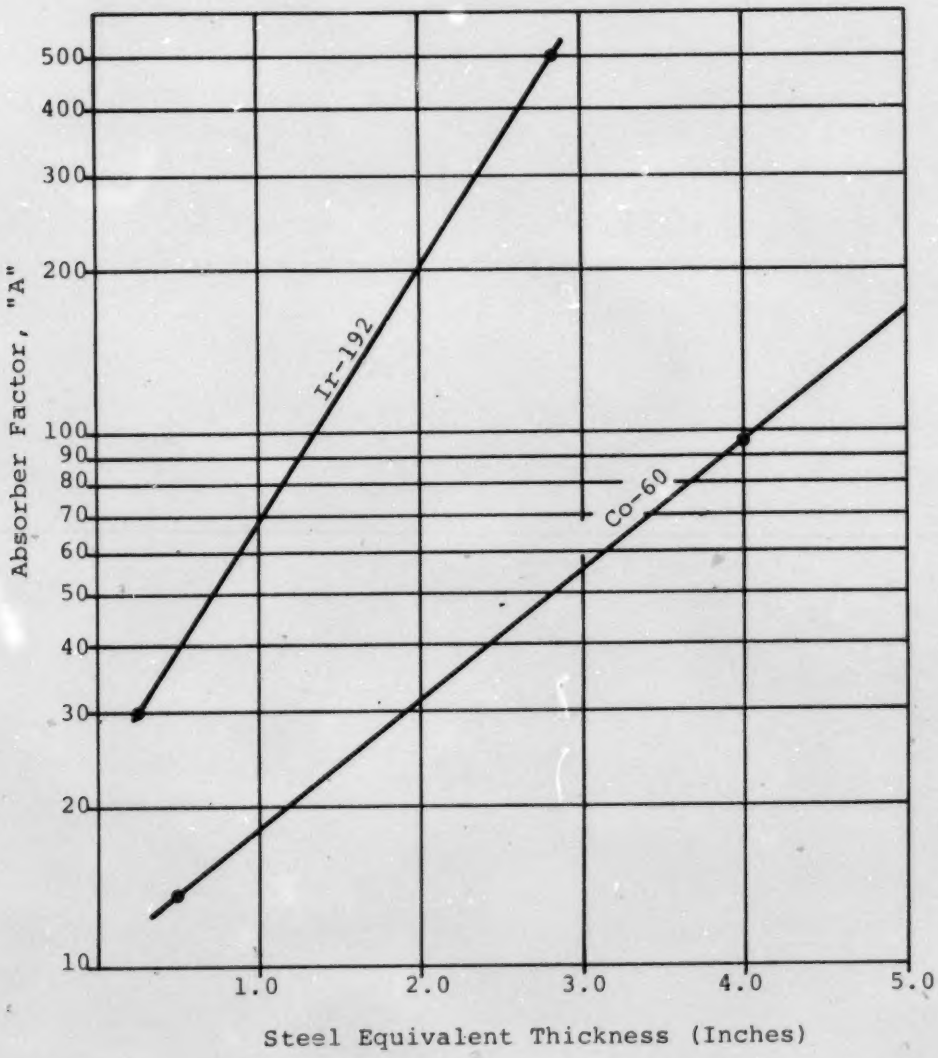


Figure 26-6-8 Absorber Values for Sources of Ir-192 and Co-60 Plotted as a Function of Steel Equivalent Thickness

plotted for a range of steel equivalent thickness and are shown in Figure 26-6-8. The steel equivalent thickness value for the specimen material can be obtained by multiplying the specimen thickness by the appropriate factor listed in chart, Figure 26-6-7.

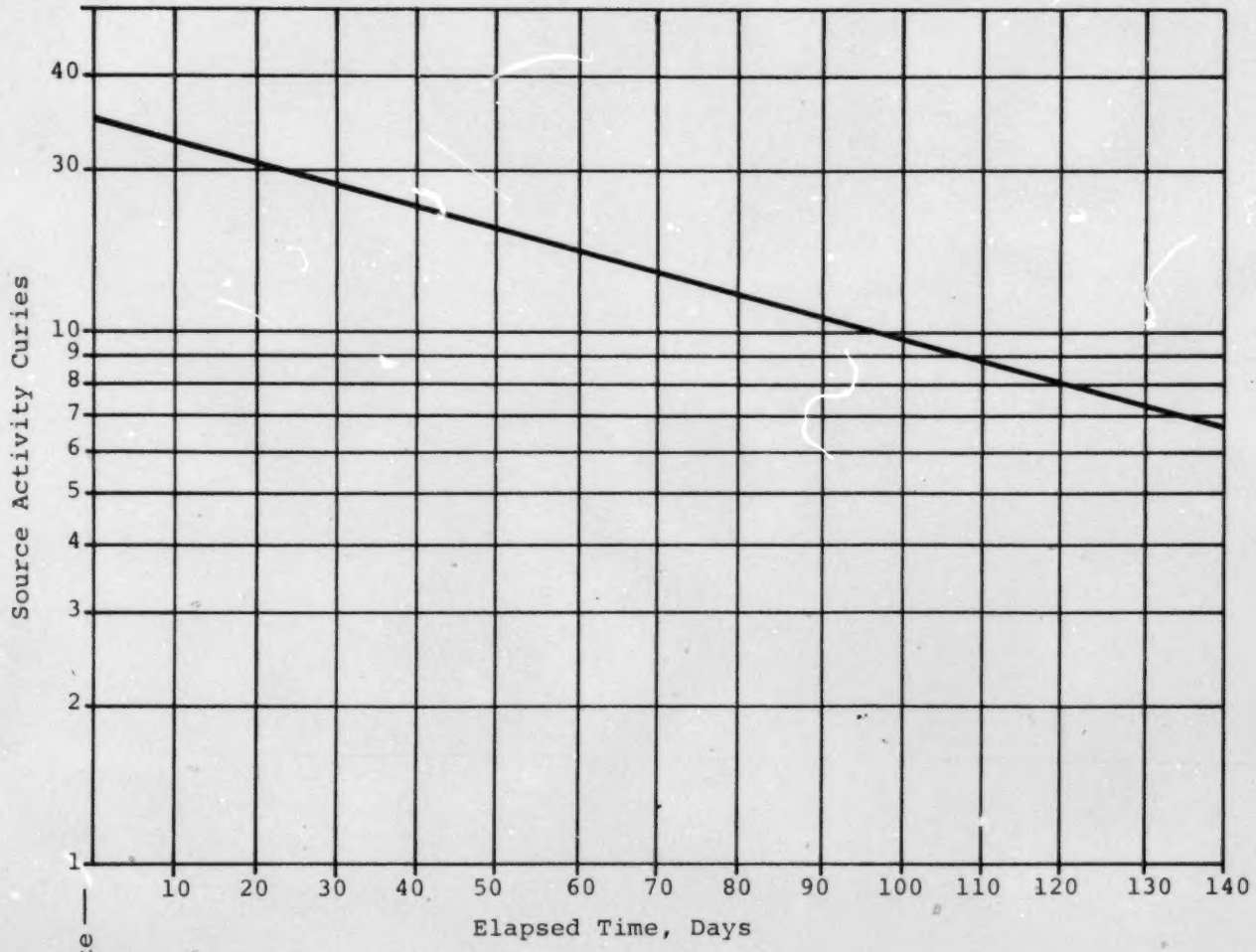
Source Emissivity

Darkening of the radiographic film is determined by the total amount of radiation reaching the film.

The total amount of radiation emitted from an x-ray tube depends on tube kilovoltage, current (milliamperage) and the time the tube is energized. The x-ray output is directly proportional to both milliamperage and time, and, therefore, is directly proportional to their product. This product is referred to as the "exposure", and is usually expressed in units of milliampere-minutes.

The total amount of radiation emitted from a gamma-ray source is approximately proportional to the source activity (usually stated in curies) and the time of the exposure. The proportional relationship of source sizes is not exact due to absorption of gamma-rays within the radioactive material itself (self-absorption). In normal practice, however, the source sizes used are not substantially different enough to cause large variations from proportionality. The variations are usually ignored, and, thus, the gamma-ray output is directly proportional to both the activity of the source and time, and is also directly proportional to their product.

When gamma-ray source is delivered to a user by the supplier, it is supplied with a dated source activity (strength) chart, such as shown in Figure 26-6-9. The chart is used to determine the source activity on the day that the exposure is to be made. For example (refer to Figure 26-6-9) on the 30th day following the date of calibration, the source activity is 19 curies.



Source: Ir-192 Half-life: 75 Days
Activity: 25 Curies
Date of Calibration: 3/31/78
Supplier: Rad-Industries
Calibrated By: R.G.

Figure 26-6-9 (Typical) Source Activity Chart

USE OF RADIOGRAPHIC SCREENS

The formation of radiographic images is governed by absorbed radiation. Usually less than 1 percent of the energy emitted from a gamma or x-ray source is absorbed by a film. The balance of the energy is wasted. Radiographic screens are usually employed to utilize part of that wasted energy and intensify the photographic action on the film.

Two types of radiographic screens are used: lead screens and fluorescent screens.

Lead screens consists of lead foil sheets thicknesses of from about 0.004 to 0.010 inches, and are used in direct contact with both sides of the film. This arrangement produces three principal effects: (1) increases the photographic action on the film, (2) absorbs longer wavelength scattered radiation, and (3) intensifies the primary radiation more than the scattered radiation.

Typically, with gamma and x-radiography, the front lead screen used is 0.005 inch, which provides the intensifying action, and the back screen is 0.010 inch, which absorbs back-scatter.

The intensification achieved with the use of lead screens depends on the material radiographed, the material thickness, and the radiation quality or kilovoltage. For example, in the radiographing of 1-1/4 inches of steel with x-rays of about 200 KV, lead screens permit an exposure of about 1/3 of that without screens, or an intensification factor of 3. In radiographing the same material with gamma rays, the intensification factor is about 2.

Fluorescent screens are thin, composite sheets consisting of special cardboard glazed with a mixture of fully powdered materials which have the ability to absorb x-rays or gamma rays and emit light (fluoresce). They are used by clamping

a radiographic film tightly between a pair of these screens during exposure. The photographic effect is intensified because it is the sum of the effects of the source radiation and the light emitted by the screens.

Fluorescent screens are seldom used in industrial radiography because they tend to give excessive graininess to the image and produce poor definition. They may be used on occasion in radiographying light metals or when economy demands significantly shorter exposure times.

CONTROLLING GEOMETRIC UNSHARPNESS

The arrangement of the position of the radiation source, specimen and film will determine the geometric unsharpness.

Two "rules of thumb" are used as guides in arranging geometry of techniques:

1. The source-to-film distance should be equal to greater than 8 times the specimen thickness. Smaller ratios than 8 will cause undesirable distortion.
2. The source-to-film distance should be equal or greater than the diagonal length of the radiograph, or as in the case of a narrow subject such as a weld zone, the length of the subject.

Examples

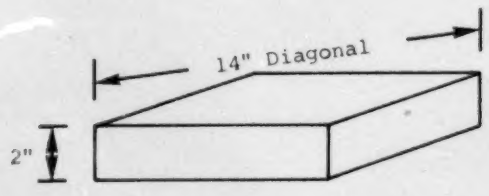


Figure 26-6-10 Steel Plate - 2" Thick, 14" Diagonal

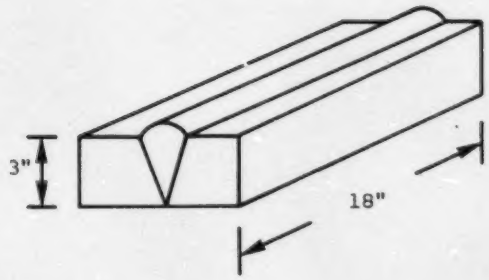


Figure 26-6-11 Welded Plate - 3" Thick, 18" Length

GAMMA RAY EXPOSURE

Many variables must be considered and controlled each time a radiograph is made. Exposure times may be determined by trial and error, but that technique is costly and time consuming. Most radiographic film manufacturers publish exposure guides for their respective films which can be used to determine approximate exposure times for the various factors of specimen material and thickness, source type and strength, and source-film distance. If these charts and guides are not available, the following calculation method may be used to determine the appropriate exposure time:

$$\underline{\text{Equation}}\ \text{A} \qquad T = \frac{FAD^2}{S}$$

Where: T = Exposure time (minutes)
F = Film factor (See chart, Figure 26-6-6)
A = Absorber factor (See curve, Figure 26-6-8)
D = Source to film distance (inches)
S = Source activity (millicuries, Figure 26-6-9)

This calculation is based on the use of lead intensifying screens in the film pack, 0.005" front, and 0.010" back.

In using Equation A, the following steps should be used:

1. Identify the material to be radiographed, and refer to Figure 26-6-7, Radiographic Equivalence Factors. For the gamma-ray source to be used (Ir-192 or Co-60) determine the steel-equivalent-thickness factor (e.g., 2024 Alum. Alloy with Ir-192, factor = 0.35).
2. Measure the specimen absorption path thickness (radiation path distance through the specimen) and convert that specimen thickness to a "steel-equivalent-thickness" by multiplying the specimen thickness by the steel-equivalent thickness-factor as determined in (1) above.
3. Determine the absorber factor "A" (for Equation A) as follows - Refer to chart, Figure 26-6-8: from the curve for the selected source (Ir-192 and Co-60) and the calculated steel-equivalent thickness, read the value of the absorber factor, "A".
4. Determine the film factor "F" (for Equation A) as follows - Refer to table, Figure 26-6-6: for the film type to be used, and the desired density, read the value of the film factor.
5. Determine the source-to-film distance, "D", in inches (for Equation A) by measuring the longest specimen dimension and the specimen thickness (for Equation A).
6. Determine the selected source activity, "S", (for Equation A) as follows - Refer to the Source Activity Chart (or Source Calibration Chart) as furnished by the source supplier. (e.g., see the Typical Source Activity Chart, Figure 26-6-9, which represents an Ir-192 source of 25 curies, when calibrated.) Count

the number of calendar days from the date of calibration to the present, and read the present source activity from the chart. Note that the chart is plotted in units of curies. Convert the value in curies to millicuries by multiplying by 1000 to obtain the source activity value "S".

7. Calculate the exposure time, "T", by substituting the numerical values into Equation A, $T = \frac{FAD^2}{S}$.

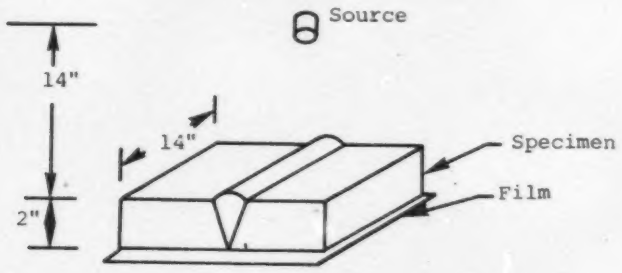


Figure 26-6-12 Gamma Ray Exposure Set-Up

Calculate the gamma ray exposure for the set-up shown in Figure 26-6-12 using the equation $T = \frac{FAD^2}{S}$, and the following materials and factors:

- Film - Medium Speed
- Density - 2.5
- Source - Ir-192 (use Source Activity Chart, Figure 26-6-9)
- Material - 2024 Aluminum Alloy

1. Determine "A", absorber factor - Refer to chart, Figure 26-6-7. For 2024 Aluminum alloy and Ir-192 source, the steel-equivalent thickness factor is 0.35. Convert the specimen thickness (2") to the steel-equivalent thickness: 2" x 0.35 - 0.70".

   Refer to chart, Figure 26-6-8. For a steel-equivalent thickness of 0.70", determine the absorber factor "A" by reading from the Ir-192 curve. "A" = 49.

2. Determine "F", film factor - Refer to table, Figure 26-6-6. For medium speed film and a desired density of 2.5, read the film factor. "F" - 6.6.
3. Determine "D", source-to-film distance - Refer to the set-up illustration, Figure 26-6-12. The specimen thickness ratio is: 2" x 8 = 16". The specimen length is 14". The minimum source-to-film distance, "D", = 16".
4. Determine "S", source activity. Refer to chart, Figure 26-6-9, for this example. Assume that 40 days have elapsed since the source was calibrated and the chart was produced. Reading from the chart, the present source activity is 17 curies. Converting this value, "S" = (17 x 1,000) = 17,000 millicuries.
5. Reiterating the factor values:

   F = 6.6

   A = 49

   D = 16

   S = 17,000
6. Substituting in the equation:

$$T = \frac{(6.6)\ (49)\ 16)^2}{17,000} = 4.87 \text{ minutes, or } 4.9 \text{ minutes}$$

X-Ray Exposure

The penetrating power of an x-ray machine is a function of x-ray tube operating kilovoltage, as formerly discussed (see Figure 26-6-1).

X-ray tubes are designed to operate at specific voltages (or kilovoltages), which vary between different manufacturers. The amount and quality of the penetrating radiation emitted from different tubes may be quite different, even though they are operating at the same current. and the same nominal

voltage. Consequently, it is difficult to formulate a mathematical relationship, or equation, that can be used to calculate precise exposure times for all types of x-ray machines. Exposure charts are usually available from the film and x-ray machine manufacturers which may be used as guides. It is usually necessary for the radiographer to make trial and error exposures and develop x-ray technique curves for using the particular x-ray machine or different films and densities. The information obtained may also be used to correct or adjust the manufacturer's charts. See typical X-Ray Exposure Chart, Figure 26-6-13. (Please see next page for Figure 26-6-13).

An x-ray tube has an energy emission rate determined by the tube current, milliamperage (ma). The film exposure is the product of the beam intensity and time in minutes (min). The exposure then is expressed in ma-min (milliampere-minutes). Up to the maximum tube current specified by the manufacturer, the radiographer may select any ma value. This selected ma value divided into the milliampere-minute obtained from the X-Ray Exposure Chart (such as Figure 26-6-13) will determine the exposure time in minutes.

Example: X-Ray Exposure Calculation

Calculate the approximately exposure for the steel specimen shown in Figure 26-6-14.

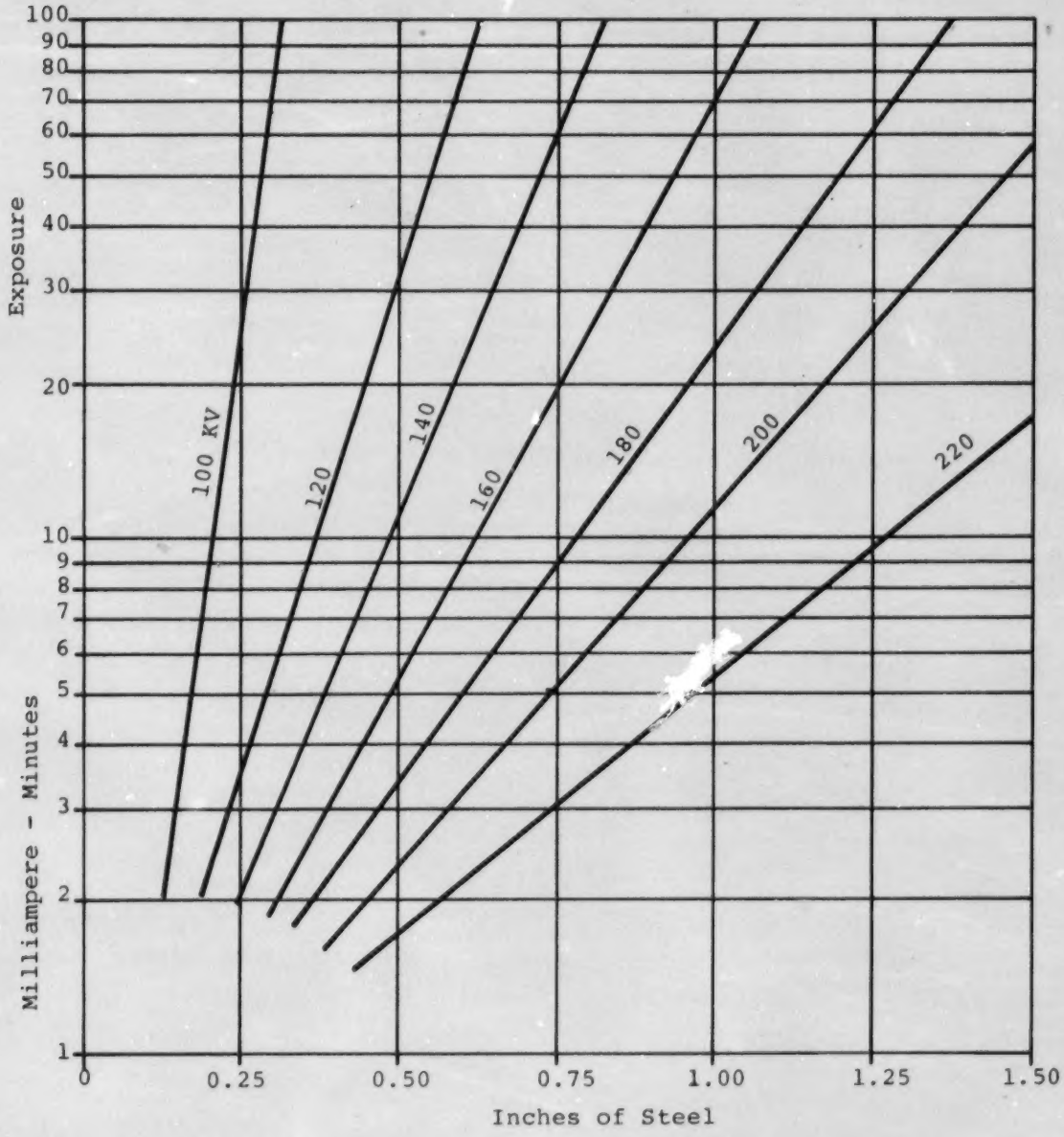


Figure 26-6-13 Typical X-Ray Exposure Chart
For: 220 KV X-Ray Machine
Film Density - 1.5 Film Speed - Fast
Material - Steel
Film Focus Distance - 40"

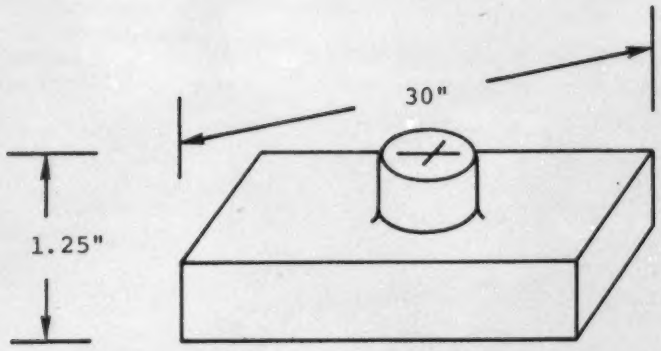


Figure 26-6-14 Machined Steel Plate With Boss

1. As Figure 26-6-14 shows, the maximum specimen thickness is 1-1/4" and the diagonal measure is 30". Applying the rules-of-thumb:
   - thickness ratio - 1.25" x 8 - 9" min source-to-film distance
   - diagonal measurement - 30" min source-to-film distance minimum source-to-film distance is 30"
2. A 220 KV x-ray machine is available for use, and a fast film has been selected for the radiograph. Refer to the X-Ray Exposure Chart, Figure 26-6-13. As the chart shows, voltage settings from 180 KV to the maximum 220 KV will penetrate the specimen. To minimize the exposure, a setting of 220 KV is selected. Reading from the chart (cure for 220 KV @ 1.25") the exposure is 9.5 ma-min.

   Notice that the chart was prepared using a source-to-film distance of 40". Since for this specimen a source-to-film distance of only 30" is being used, the radiant energy will be more intense, and a correction must be made. Using the inverse square law:

$$\frac{(ma - min)_1}{(ma - min)_2} = \frac{D_1^2}{D_2^2}$$

Where: $(ma - min)_1 = 9.5$

$(ma - min)_2$ = unknown

$D_1 = 40$

$D_2 = 30$

Substituting in the equation,

$$(ma - min)_2 = \frac{(9.5)\ (30)^2}{(40)^2} = 5.34 \text{ ma - min}$$

If the milliamperage control is set for 5 ma, the exposure time "T" is calculated as follows:

$$T = \frac{5.34 \text{ ma - min}}{5 \text{ ma}} = 1.07 \text{ min, or 1 min. 4 sec.}$$

CONTROL OF SCATTER

Scattered radiation cannot be completely eliminated, but may be reduced to minimize loss of image resolution.

The most convenient and least expensive method of combatting the effects of scattered radiation is the use of lead screens, as previously described. Lead screens mounted in contact with both sides of the film reduce the scatter reaching the film regardless of whether the screens permit a decrease or necessitate an increase in the radiographic exposure.

For thick specimens or specimens having high absorption of x-rays or gamma rays, the scattered radiation from external sources may be high compared to the primary radiation reaching

the film through the specimen. Such scatter may be reduced by the use of a sheet lead mask cut-out and placed around the specimen.

Lead diaphragms may be used near the radiation source to limit the cross-section of the primary beam to the shape or size of the specimen, and may be used to mask unwanted parts of a specimen when only a part of the specimen is to be radiographed, thereby minimizing the scattered radiation.

EXPOSURE ARRANGEMENTS

The quality of the radiograph is determined by the proper location of the source and film with respect to the specimen.

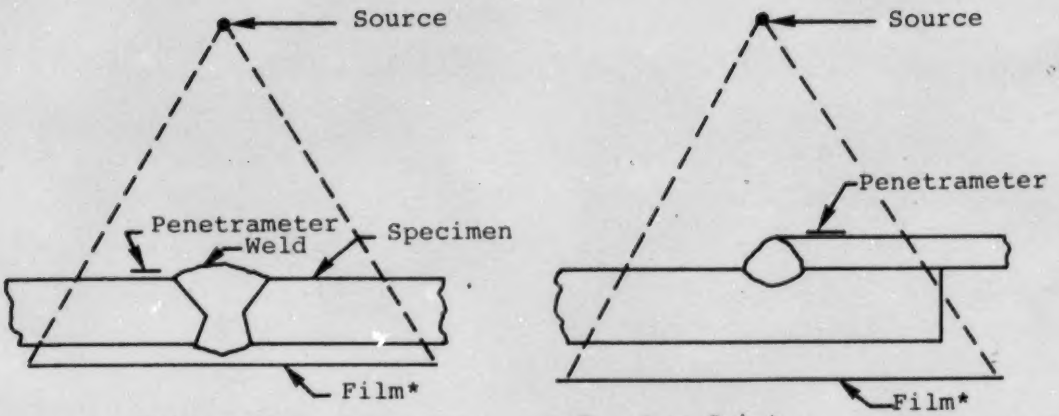
The exposure arrangement should be selected by the radiographer to:

1. Produce the best radiographic contrast of the specimen area that is likely to contain manufacturing discontinuities.
2. Produce the best radiographic contrast of the specimen area that is likely to fail in service (under imposed operating stresses).
3. Permit the shortest exposure time.

Typical industrial situations and arrangements are shown as follows:

Welded Flat Plates

A flat weld area such as shown in sketch A and sketch B in Figure 26-6-15 represents subjects easily radiographed, with the critical areas well defined in length, width and thickness, with minimal subject contrast.



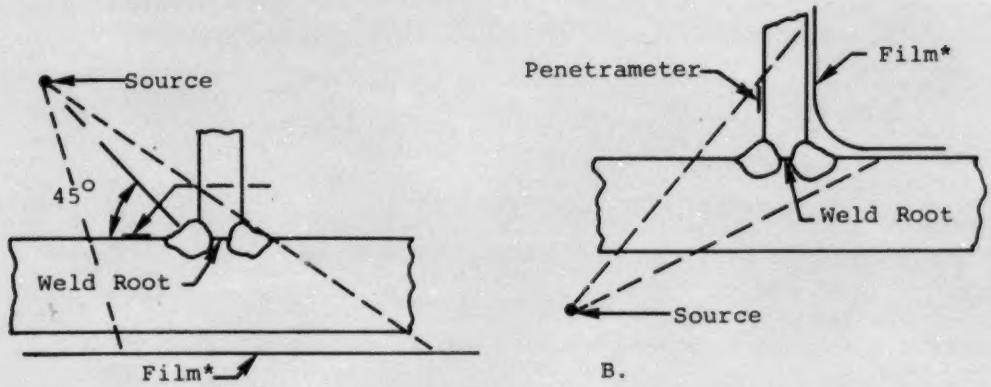
*Note: Film packed with 0.005", front and 0.010" back lead screens.

Figure 26-6-15 Flat Welded Plates

Welded tee joints such as those shown in Figure 26-6-16, present different problems. The weld root is the area most likely to contain defects, yet no convenient location for the film can be found that will give good weld room image resolution. Either arrangement A or B can be used. It should be noted, however, that the object (weld zone) - film distance is quite large in sketch A, and that a very long source-to-film distance is required to produce good resolution. (Please refer to the next page for Figure 26-6-16.)

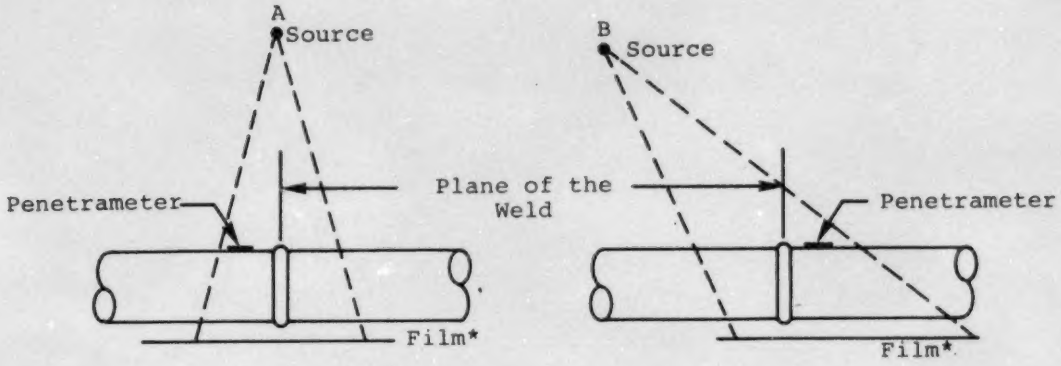
Weld Joints of Pipe

Small pipe welds, i.e., 1-1/2" or less, can usually be radiographed with the entire weld exposed on a single film, as shown in Figure 26-6-17. With the source a location "A", however, the images of both front and back pipes walls are projected onto the same film area, where it would not be possible to determine which wall contained a defect



*Note: Film packed with 0.005" front and 0.010" back lead screens.

Figure 26-6-16 Welded Tee Joint on Plate



*Note: Film packed with 0.005" front and 0.010" back lead screens.

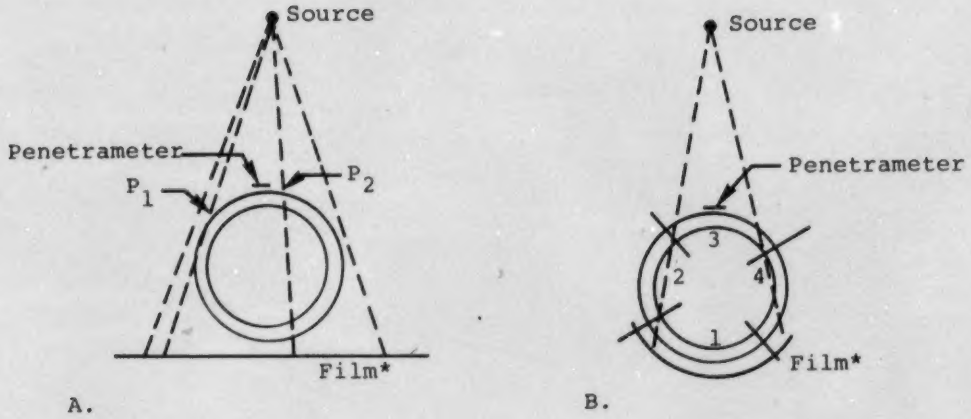
Figure 26-6-17 Large Pipe Welds (Profile)

if one were present. A better arrangement is to off set the source from the plane of the weld, such as at location B, thereby producing an elliptical weld image which will reveal the location of existing weld discontinuities.

Large pipe welds, i.e., over 1-1/2", can seldom be radiographed successfully with only one exposure. One problem encountered by the radiographer is that it is difficult to determine the effective length of the radiation path through the specimen for calculating exposure time. Sketch A in Figure 26-6-18 illustrates that the material thickness along radiation path P_1 is much greater than at path P_2. The resulting radiograph will be much darker in area P_2 than at P_1; i.e., when one area of the radiograph is exposed to the required density of other areas will be either too light or too dark. Acceptable radiographs of the pipe can be obtained by dividing the weld circumference into 3 or 4 segments, as shown in sketch B of Figure 26-6-18, and radiographing each with a separate exposure. If the pipe has diameter 12 inches or greater and its interior is accessible, it can usually be radiographed with one exposure by wrapping the film around the exterior or circumference and placing the radiation source internally at the center. This technique is also used in pressure vessel radiography.

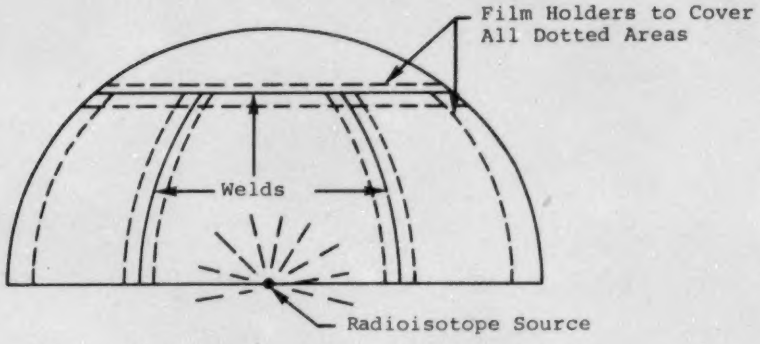
Hemispherical "Orange Peel" Head

An efficient method of radiographing the welds on spherical and hemispherical pressure vessels is illustrated in Figure 26-6-19. Film holders are placed over the weld areas as shown, the source placed at the geometric center, and all films exposed simultaneously with the 360^{o} beam.



*Note: Film packed with 0.005" front and 0.010" back lead screens.

Figure 26-6-18 Large Pipe Welds



Notes:

1. Penetrameters placed on shell interior, adjacent to welds.
2. Film holders placed on shell exterior.
3. Film packed with front and back lead screens.

Figure 26-6-19 Hemispherical "Orange Peel" Head

Panoramic Exposure

When groups or large numbers of small, similar parts are to be radiographed, a panoramic exposure arrangement may be used as shown in Figure 26-6-20. The parts, with penetrameters and film packs, are arranged in a circular array around the source, and all exposed simultaneously.

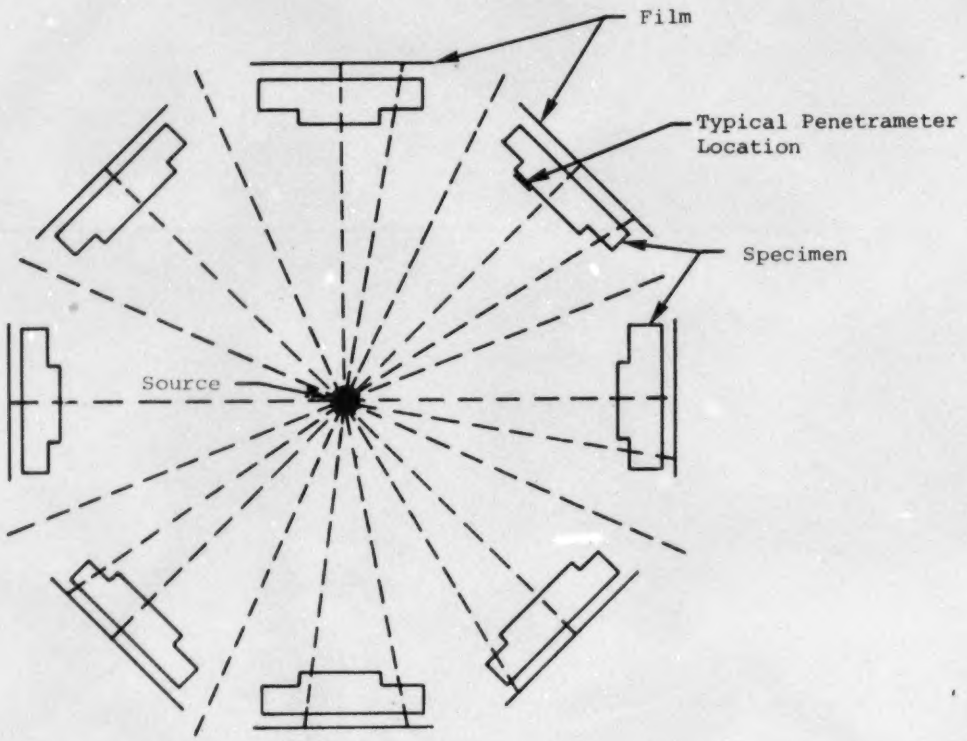


Figure 26-6-20 Panoramic Exposure Arrangement

Multiple Exposure or Multiple Film

On specimens with large subject contrast (or large thickness differences) it may not be possible to produce a radiograph with acceptable density in all areas, with one exposure on one film. This problem may be resolved by using one of the following techniques:

1. Multiple exposures, as illustrated in Figure 26-6-21, using the same film may be made, with the source and the film for each arrangement adjusted to produce the optimum exposure and radiograph for each particular section of the specimen.

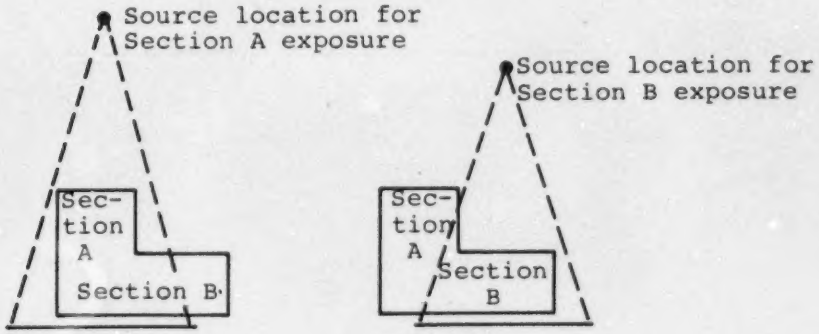


Figure 26-6-21 Multiple Exposure Technique

2. Multiple films (usually 2) of the same type may be loaded into the same film pack and exposed simultaneously, as shown in Figure 26-6-22. When viewing and reading the finished radiograph, the two films are superimposed and read together for the area representing the thick section of the specimen, and the films are read individually for the area representing the thin section (the radiograph of a thin section will be darker (denser) than a radiograph produced with the same exposure of a thick section).

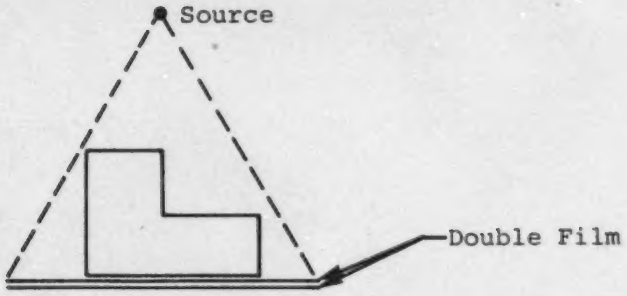


Figure 26-6-22 Multiple Film (Same Type) Technique

3. Multiple films (usually 2) of different speeds or sensitivities may be loaded into the same film pack and exposed simultaneously as shown in Figure 26-6-23. The exposure can be adjusted so that the slow film produces a radiograph of acceptable density for the thin section of the specimen, and the fast film produces a radiograph of acceptable density for the thick section of the specimen.

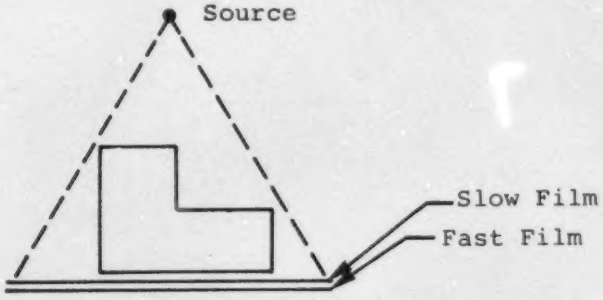


Figure 26-6-23 Multiple Film (Slow/Fast) Technique

FILM PROCESSING AND HANDLING

The film processing operations of development, stop bath, fixation, washing and drying are covered in Module 26-5, "Fundamentals of Radiography", along with the descriptions of typical equipment used.

A primary consideration in film handling and processing operations is cleanliness. The processing area or room and all accessories and equipment must be kept scrupulously clean to preclude damage to film or contamination of processing chemicals.

Careful handling by the radiographer will minimize such physical film damage as scratches, crimp marks, and pressure marks, all of which can occur during the loading and unloading of film holders, film cassettes, and automatic processing equipment.

UNSATISFACTORY RADIOGRAPHS: CAUSES AND CORRECTIONS

Errors in technique or the mishandling of radiographic materials may result in unsatisfactory radiographs. Scratches, marks or other blemishes on the film, and images on the film resulting from foreign material, static electricity or sources other than the specimens may be viewed and interpreted as apparent discontinuities in the specimen. These apparent discontinuities are known as artifacts and must be identified as irrelevant indications during the film reading and interpretation phase of the examination. Some of the common quality defects and artifacts found in finished radiographs are listed in Table 1, with their probable causes and suggested corrective actions. In all cases, and radiographer should try to identify the cause and prevent a recurrence.

TABLE 1

IMAGE QUALITY DEFECTS AND ARTIFACTS IN FINISHED RADIOGRAPHS
WITH PROBABLE CAUSES AND CORRECTIVE ACTIONS

IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION	IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION
Density too high	Overexposure	View with higher intensity light. Check exposure (time and radiation intensity); if as specified, reduce exposure 30% or more.	Contrast too high	High subject contrast	Increase tube voltage.
				High film contrast	Use a film with lower contrast characteristics.
			Contrast too low	Low subject contrast	Reduce tube voltage
	Overdevelopment	Reduce development time, or reduce developer temperature.		Low film contrast	Use a film with higher contrast characteristics.
				Underdevelopment	Increase development time or developer temperature. Replace weak (depleated) developer.
	Fog	See "Fog".			
Density too low	Underexposure	Check exposure (time and radiation intensity); if as specified, increase exposure 40% or more.	Poor definition	Test-piece-to-film distance too long	If possible, decrease test-piece-to-film distance; if not, increase source-to-film distance.
	Underdevelopment	Increase development time or developer temperature. Replace weak (depleated) developer.		Source-to-film distance too short	Increase source-to-film distance.
	Material between screen and film	Remove material.		Focal spot (or gamma-ray source) too large	Use smaller source or increase source-to-film distance. (Continued)

TABLE 1 (Continued)

IMAGE QUALITY DEFECTS AND ARTIFACTS IN FINISHED RADIOGRAPHS
WITH PROBABLE CAUSES AND CORRECTIVE ACTIONS

IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION
Poor definition (Continued)	Screens and film not in close contact	Ensure intimate contact between screens and film.
	Film graininess too coarse	Use finer-grain film.
Fog	Light leaks in darkroom	With darkroom unlighted, turn on all lights in adjoining rooms; seal any light leaks.
	Exposure to safelight	Reduce safelight wattage. Use proper safelight filters.
	Stored film inadequately protected from radiation	Attach strip of lead to loaded film holder and place in film-storage area. (Continued)
Fog (Continued)		Develop test film after 2 to 3 weeks; if image of strip is evident, improve radiation shielding in storage area.
	Film exposed to heat, humidity, fo gases	Store film in a cool, dry place not subject to gases or vapors.
	Overdevelopment	Reduce development time, or reduce developer temperature.
	Developer contaminated	Replace developer.
	Exposure during processing	Do not inspect film during processing until fixing is completed.
Finely mottled fog	Stale film	Use fresh film.
Fog on edge of corner	Defective cassette	Discard cassette.
Yellow stain	Depleted developer	Replace developer solution. (Continued)

TABLE 1 (Continued)

IMAGE QUALITY DEFECTS AND ARTIFACTS IN FINISHED RADIOGRAPHS
WITH PROBABLE CAUSES AND CORRECTIVE ACTIONS

IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION
Yellow stain (Continued)	Failure to use stop bath or to rinse	Use stop bath, or rinse thoroughly between developing and fixing.
	Depleted fixer	Replace fixer solution.
Dark circular marks	Film spashed with developer prior to immersion	Immerse film in developer with care.
Dark spots or marble-like areas	Insufficient fixing	Use fresh fixer solution and proper fixing time.
Dark branched lines and spots	Static discharge	Unwrap film carefully. Do not rub films together. Avoid clothing productive of static electricity.
Dark fingerprints	Touching undeveloped film with chemically contaminated fingers	Wash hands thoroughly and dry, or use clean, dry rubber gloves.
Light fingerprints	Touching undeveloped film with oily or greasy fingers	Wash hands thoroughly and dry, or use clean, dry rubber gloves.
Dark spots or streaks	Developer contaminated with metallic salts	Replace developer solution.
Crescent-shape light areas	Faulty film handling	Keep film flat during handling. Use only clean, dry film hangers.
Light circular patches	Air bubbles on film during development	Agitate immediately upon immersion of film in developer.

TABLE 1 (Continued)

IMAGE QUALITY DEFECTS AND ARTIFACTS IN FINISHED RADIOGRAPHS
WITH PROBABLE CAUSES AND CORRECTIVE ACTIONS

IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION	IMAGE QUALITY OR ARTIFACT	PROBABLE CAUSE	CORRECTIVE ACTION
Circular or drop shape light patches	Water or fixer splashed on film before development	Avoid splashing film with water or fixer solution	Frilling (loosening of emulsion from film base)	Fixer solution too warm	Maintain correct temperature of the fixing solution.
				Fixer solution depleted	Replace fixer solution.
Light spots or areas	Dust or lint between screens and film	Keep screens clean.	White scum	Improperly mixed fixer solution (mixed too warm, too rapidly	Replace fixer, properly mixed.
Sharply outlined light or dark areas	Nonuniform development	Agitate film during development.		Fixer solution contaminated with developer	Replace fixer.
Reticulation (leather-grain appearance)	Temperature gradients in processing solutions	Maintain all solutions at uniform, constant temperature.			

EXERCISES

Due to the special safety precautions which must be exercised in using radiographic test equipment laboratory exercises using this equipment are not suggested for this module. However, a field trip to either a manufacturing site, nuclear power plant or construction site employing radiography is suggested. Therefore, to reinforce the concepts presented in this module the following exercises are suggested.

1. Visit a facility or construction site and observe the use of radiographic non-destructive examination techniques in action. Prepare a report as outlined in the Procedures section of this module.

2. Using Figure 26-6-1 perform the following exercise: For radiography steel specimens using lead screens in the film packs, determine the x-ray tube voltage required for a steel thickness of:
   a. 2 inches _____
   b. 4½ inches _____

3. Using Figure 26-6-3 perform the following exercise: Determine which radiation sources shown in Figure 26-6-3 are suitable for radiographing a 4½ inch thick steel specimen.

4. Explain how radiographic films are classified.

5. Explain the purpose(s) of loading lead screens into film packs.

6. Refer to Figure 26-6-7 in performing the following exercise:
Using the factors listed on the chart, calculate the steel equivalent thickness (S.E.T.) for the following specimens.

a. 3" Steel, 1000 KV X-Ray S.E.T. = _____
b. 4" Copper, Co-60 S.E.T. = _____
c. 6" 2024 Alum., Co-60 S.E.T. = _____

7. Refer to Figure 26-6-8 in performing the following exercise:
Using the equivalent curve, determine the "A" factor for the following steel equivalent thickness values:

a. 1" with Ir-192 A = _____
b. 2.5" with Ir-192 A = _____

8. Calculate the minimum source-to-film distance for the following object:
Round Plate
13" diameter
1-1/2" thick
Min. Source-to-Film Distance _____

9. Calculate the gamma ray exposure time for the following arrangement (factors are given):
F = 6.6
A = 40
D = 20 inches
S = 10 curies

T = _____ minutes

10. Calculate the x-ray exposure required for the following specimen and arrangement:
Specimen: Steel, 1" thick, 10" diagonal measure
X-Ray Machine: 160 KV maximum

Notes: (1) Use minimum "rule-of-thumb" source-to-film distance.
(2) Use chart, Figure 26-6-13 for reference.

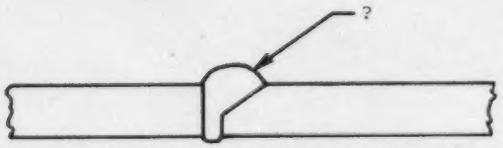
Exposure = _____ ma - min

11. Explain why the weld root is a potential area to contain a defect and this area should be observed carefully during the radiographic testing.

12. Explain why it is good to have multiple exposures of pipe welds using the radiographic inspection technique.

13. Panoramic exposure arrangements are best for radiographing a number of similar or identical parts which can be arranged conveniently around a radiation source. Briefly explain why this is so.

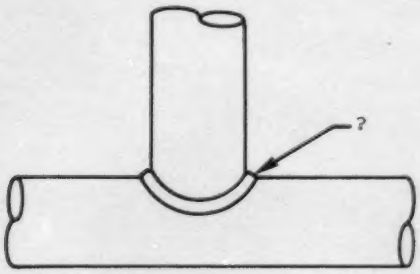
14. Label the following sketch of butt weld plates.



Butt Welded Plates

Label:
1. Source Location
2. Penetrameter Location
3. Film Location

15. Label the following sketch of a weld "Tee" pipe joint.



Welded "Tee" Pipe Joint

Label:

1. Source Location(s)
2. Penetrameter Location(s)
3. Film Location(s)
4. Number of Exposures Required to Radiograph Entire Weld

16. Unsatisfactory radiographs can and do occur in practice. Table 1 lists quality defects in finished radiographs. Using Table 1, list the effect on the film or image quality for the errors in technique listed as follows:

Error	Effect on the Film or Image Quality
a. Film overdevelopment	_____
b. Static discharge	_____
c. Overexposure	_____
d. Underexposure	_____
e. Exposure to scattered radiation	_____
f. Depleted developer or fixer	_____
g. Screens and film not in close contact	_____
h. Handling undeveloped film with oily fingers	_____
i. Extreme subject contrast	_____
j. Nonuniform development	_____

MATERIALS

None.

PROCEDURES

1. Visit a facility or construction site which uses radiographic non-destructive examination techniques. Prepare a report which includes discussion of the following:
   a. Name and location of the site visited.
   b. Date of visit.
   c. Type(s) of radiographic NDE techniques employed.
   d. A sketch of a typical NDE setup using a radiographic technique.
   e. Type of records kept on the radiographic inspections performed.
   f. Description of the radiological safety measures used for the personnel employed at the site.

DATA TABLE

None.

REFERENCE MATERIALS

Eastman Kodak Company. Radiograhy in Modern Industry, 1969

McGonnagle, Warren J., Nondestructive Testing, New York: McGraw Hill Book Company

Metals Handbook, Volume 11, Nondestructive Inspection and Quality Control, American Society for Metals

McMaster, Robert C. (ed.) Nondestructive Testing Handbook, New York: The Ronald Press Company

Overman Ralph T., Basic Concepts of Nuclear Chemistry, New York: Reinhold Publishing Corporation

TEST

1. Using Figure 26-6-1, answer the following question:
   For radiography steel specimens using lead screens in the film packs, determine the x-ray tube voltage required for a steel thickness of:
   a. 2½ inches _____
   b. 5 inches _____

2. Using Figure 26-6-3, answer the following question:
   Determine which radiation sources shown in Figure 26-6-3 are suitable for radiographing a 3½ inch thick steel specimen.

3. Mark the following statements true of false:
   a. Higher x-ray tube voltages produce greater penetrating power. _____
   b. The gamma energy emitted by a radioisotope has a direct effect on the penetrating power. _____
   c. An Iridium-192 source has greater penetrating power than a similar size Cobalt-60 source. _____
   d. In x-radiography, film contrast is not influenced by tube kilovoltage _____
   e. Ir-192 cameras are usually much larger and heavier than Co-60 cameras. _____

4. Complete the following statements:
   a. Radiographic films are classified by _____ and _____.
   b. Industrial radiographic films are designed to produce _____ and _____ than medical type films.

5. Mark the following statements true or false.

a. Bulk film sheets may be handled safely in daylight. _____

b. Film sheets may be protected from static discharges by handling carefully and slowly. _____

c. Lead screens are loaded into film packs when using intensification techniques. _____

d. New film is only sensitive to x-radiation in storage after the sealed film carton has been opened. _____

6. Refer to Figure 26-6-7 in answering the following question:

Using the factors listed on the chart, calculate the steel equivalent thickness (S.E.T.) for the following specimens.

a. 1/2" Zirconium, 220 KV X-Ray S.E.T. = _____

b. 2" 2024 Alum., Ir-192 S.E.T. = _____

7. Refer to Figure 26-6-8 in answering the following question.

Using the equivalent curve, determine the "A" factor for the following steel equivalent thickness values:

a. 2.2" with Co-60 "A" = _____

b. 4.5" with Co-60 "A" = _____

8. Calculate the gamma ray exposure time for the following arrangement (factors are given):

F = 14.9 D = 2.5 feet

A = 50 S = 100,000 millicuries

T = _____ minutes

9. Use Figure 26-6-7 in answering the following questions:
   a. What was the source activity at the time of calibration or chart preparation?

      _____

      _____

   b. What is the source activity 54 days after calibration?

      _____

      _____

   c. After how many days from the calibration date will the source activity decrease to 6.25 curies?

      _____

      _____

10. The use of lead screens with radiographic film produces which of the following effects:
   a. increases photographic action, or film darkening ____
   b. absorbs scattered radiation ____
   c. intensifies primary radiation ____
   d. all of the above ____

11. Calculate the minimum source-to-film distance for the following object:

   Rectangular Plate

   2" wide x 8" long (8.25" diagonal)

   3" thick

   Min. Source-to-Film Distance _____

12. Mark the following statements true or false:
   a. In radiographing weld joints the area least likely to contain defects in the weld root. _____
   b. All pipe welds should be exposed with a single film technique to keep the number of stored films to a minimum. _____

c. Panoramic exposure arrangements are best _____
for radiographing a number of similar or identical parts which can be arranged conveniently around a radiation source.

d. Multiple film techniques are frequently used _____
on welded flat plates.